

AD-A116 598

CENTER FOR NAVAL ANALYSES ALEXANDRIA VA OPERATIONS EV--ETC F/6 12/1
APPLIED MATHEMATICIANS AND NAVAL OPERATORS. REVISED.(U)
MAR 82 M MANGEL

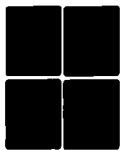
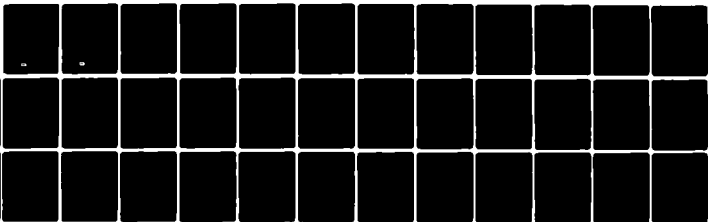
N00014-76-C-0001

UNCLASSIFIED

CNA-PP-329-REV

NL

For I
AD-A116 598



END
DATE
FILMED
7-82
DTIC

AD A116598

PROFESSIONAL PAPER 329
Revised / March 1982

2

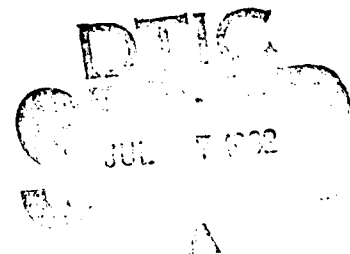
APPLIED MATHEMATICIANS AND NAVAL OPERATORS

Marc Mangel

DTIC FILE COPY



CENTER FOR NAVAL ANALYSES



For public release and sale; its
distribution is unlimited.

82

07

06

041

PROFESSIONAL PAPER 329
Revised / March 1982

APPLIED MATHEMATICIANS AND NAVAL OPERATORS

Marc Mangel

N00014-76-C-0001

✓



Operations Evaluation Group

CENTER FOR NAVAL ANALYSES

2000 North Beauregard Street, Alexandria, Virginia 22311



A

APPLIED MATHEMATICIANS AND NAVAL OPERATORS

Dedicated to Philip Morse on the Fortieth Anniversary of
the Antisubmarine Warfare Operations Research Group

Marc Mangel


Department of Mathematics

University of California

Davis, CA 95616

ABSTRACT

This is a personal view of applied mathematics in a truly nonacademic setting (an operational Navy Command), based on my experiences as a field representative of the Operations Evaluation Group. The principles that can make analysis effective in such a setting are described and explained. The intermeshing of people and personality is as important as the fields themselves. The traits that a mathematician needs to effect change by his analysis are discussed. A number of specific examples are provided to illustrate the kinds of problems that can be encountered.



"Those who have learned only how to apply some given theoretical framework to the solving of problems which arise within this framework, and which are soluble within it, cannot expect that their training will help them much in another specialism. It is different with those who have themselves wrestled with problems, especially if their understanding, clarification, and formulation, proved difficult....those who have wrestled with a problem may be compensated by gaining an understanding of fields far removed from their own....there are no subject matters but only problems....which almost always need for their solution the help of widely different theories."

--Karl R. Popper, Objective Knowledge
(Oxford University Press), pg. 182.

1. Introduction

Although this purports to be a paper about nonacademic applied mathematics, it is really about the interaction of applied mathematicians and naval operators. By "operator," I mean an individual whose job involves some part of naval action, e.g. navigating a ship, flying an aircraft, running a radar, etc. The wording is important, because I believe that when applied mathematics is done in a nonacademic setting, the intermeshing of people is as important as the fields or techniques involved. The nonacademic setting for me was an operational naval command at Whidbey Island, Washington, where I worked as the Operations Evaluation Group field representative for a period of 18 months. Hence, this is a personal view, but I think that much of what will be said here translates to other fields with little or no change.

Very often in research, the actual process of doing research is more satisfying than the particular problem being studied. It is for this reason that nonacademic applied mathematics can be so rewarding. But there is a serious pitfall, one that should be acknowledged from the outset. It is difficult to describe this kind of work without its appearing to be trivial. And often the more applied a problem is, the more mathematically trivial it may be. This runs against the training we receive in mathematics that "harder is better."

On the other hand, in many applied problems the real difficulty and the intellectual challenge are in finding and characterizing the problem in the first place, not in solving it. The harder-is-better syndrome is a pitfall that can be overcome, once one is aware of it. Of course, one will not become "famous" in the applied mathematics community by solving problems that appear to be easy. This is another trade-off that must be considered.

In the next section, I describe the Operations Evaluation Group (OEG), one of the oldest organizations in the United States doing operations research and one of the few that is still problem, rather than technique, oriented. I discuss the principles that make OEG effective. In section 3, I discuss the problems that naval operators face. They are generally operational, not technical ones, and require useful, immediate solutions. In section 4, I describe what I believe an applied mathematician can offer to the operators in terms of approach and outlook. In section 5, three examples of problems that I worked on are given. There are many other examples alluded to, but these three capture the essence of the work.

At the outset, I wish to thank many officers and enlisted men and women who helped me, especially LCdr. Bill Headridge and Capt. Paul Hollandsworth, whose efforts made my tour a success, and who are now my good friends. I also thank RAdm. Henry Arnold, who as the commander at Whidbey created such a good working environment.

2. The Operations Evaluation Group

Operations research in the United States began in 1942, with the formation of the Antisubmarine Warfare Operations Research Group (ASWORG), headed by Philip Morse. The history of ASWORG is described in Morse's book [1]. Morse collected a group of scientists and mathematicians, including George Kimball, Bernard Koopman and William Shockley, to work on various problems associated with German submarine operations off the Atlantic Coast. The group was very successful; some of its work is described in reports issued in the late 1940s, [2 through 4]. After World War II, ASWORG became the Operations Evaluation Group (OEG), and in 1962 OEG and the Institute of Naval Studies were merged to form the Center for Naval Analyses (CNA).

Operations research was created in the turmoil of a war to solve problems. The point of ASWORG was to bring a scientific approach to Naval problems, not to find problems that could be solved by a certain set of techniques.

The breadth of the staff of ASWORG caused many different techniques to be used in the solving of problems of interest to the Navy. Today, operations research is codified, much to its detriment [5 and 6]. When operations research is mentioned, people usually think of a set of techniques (e.g., linear programming, optimization, queuing theory, etc.) rather than a viewpoint about problem solving. This may

be due, in part, to the introduction of academic departments of operations research [5 and 6]. However, the old-style, problem-solving approaches of operations research are still being used by OEG and other similar organizations.

During the first few years of ASWORG, a number of principles for effective analysis emerged. Although these principles were never stated as such, they have been used to guide OEG for 40 years. My view of the principles is this:

2.1. Principle of Closeness: The Analyst Must be Near the Problem. It was discovered early in ASWORG's work that the analysts could do much more for the Navy if they were at the scene of the problem--where they could see the equipment in operation and talk with the operators about the problems--than if they were at a desk 2,000 miles away. This observation led to the OEG field program, in which analysts leave the home office for 1 to 3 years and go to work at the Naval Command. They are attached to the staff at the Command and work as theoreticians for the operators.

2.2. Building Confidence. In general, operators feel that analysts do not have much to offer them, and it is up to the analyst to find simple ways of convincing the operator that analysis is useful and that he (the analyst) cares about the problems of the operator. There are many different ways to build confidence. In my case, for example, I

won the confidence of one operator by writing a program for the HP-69 pocket calculator that allowed him to do calculations on the machine in 30 minutes that took him 4 hours the day before; of another operator by showing how to use the central limit theorem to estimate how many trials of a test were needed to gain a certain accuracy; and of an entire squadron of aviators by showing them how to calculate when a typhoon would hit the carrier we were on. I did this by fitting a simple quadratic to give distance between us and the typhoon as a function of time.

2.3. Interaction at all Levels. The third principle established during World War II was that the analyst should be able to interact easily with all levels of the Navy. For this reason, it is helpful if the analyst is a civilian instead of an officer. Admirals make decisions, but it is the junior officers who know the operations of the equipment intimately, and it is the enlisted technicians who have insights into technical problems and into problems of maintenance and reliability. In my case, for example, I found it very important to consult with the enlisted men while designing data-collection sheets for the analysis of the effectiveness of a new type of sensor. They guided me into areas that few of the officers were aware of.

2.4. Hemibel Thinking. A complicated analysis that leads to a 2 percent increase in effectiveness of operations is generally not worth doing. In the early years of ASWORG, it was agreed that if the actual

value of an operation was within a factor of 3 (i.e., 1 hemibel) of the theoretical value, a change in operation would be unlikely to improve the result. Perhaps this overstates the case for present-day operations analysis, but not by much. The goal of the analysis, after all, is understanding, prediction, and improvement in system performance.

3. Problems of Naval Operators

The problems faced by the operators can be characterized as follows. First, the problems are operational, not technical or design. The operator has a piece of equipment that undoubtedly could be improved, but he needs to figure out how to use it today. An analyst who tells him how to improve the equipment without telling him how to use today's equipment only angers and alienates the operator. For example, the EA-6B is a sophisticated electronic warfare aircraft first built for use in Viet Nam. There are presently two versions of the aircraft used in the fleet; they differ mainly in the automated nature of the detection and identification process. Two other versions that will be even more automated are being designed. These new aircraft will reduce the operators' workload considerably. The operators, however, need tactics for the present-day aircraft, not for the superior ones down the line.

The second characteristic of the problems is that although operators are looking for good ways of doing their jobs, optimizing some mathematical criterion is not their goal. This is especially important because most soluble mathematical optimization problems have little to do with the real operation. In H. Simon's language [7 and 8], they are seeking to satisfy rather than optimize. An example of this phenomenon arises in search theory. Searches are conducted almost every day by Naval operators, and starting in World War II, the theory of search developed into a mathematical subject of complexity and sophistication [4 and 9]. In the development of search theory, the idea of optimal search has played a central role. Yet, the operators often do not care if they have an optimal search plan--they just want one that is "not too bad." They need a figure like figure 1 and want to know if life follows curve A or curve B. This will determine how close to the optimum their plan needs to be for it to be adequate.

The third characteristic of the problems is that there are always stochastic factors present in the world and often deterministic biases that may be larger, generally unknown, and very hard to deal with. The presence of stochastic fluctuations and unknown deterministic biases makes it impossible to approach problems as if life were predictable and controllable from the outset. I shall provide two examples of this phenomenon in section 5.

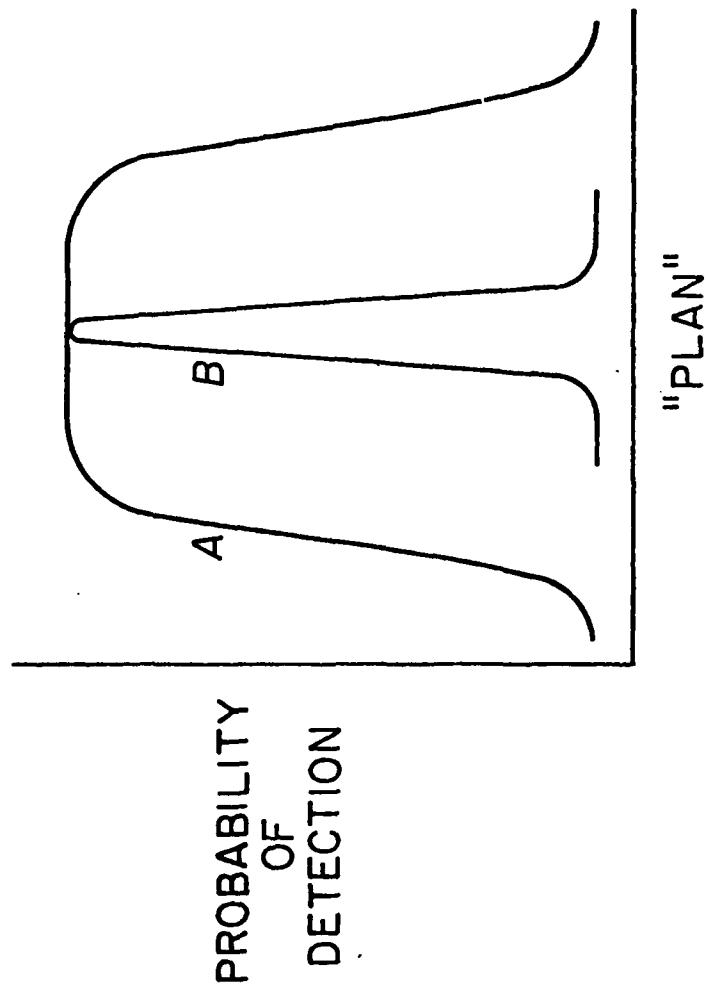


FIG. 1: A SCHEMATIC THAT THE OPERATORS NEED CHARACTERIZING
PROBABILITY OF DETECTION AND SEARCH PLAN

Two characteristics concern the operators themselves. They are not mathematicians, but after they are convinced that the analyst cares, often they can see the value of a well-presented analysis. Often the problems tackled by the analyst require only algebra, elementary statistics, and calculus. There are many officers who have these tools and lack the confidence to use them, but they can appreciate the analysis.

Finally, the good operators often have some sort of model of the problem of interest. It is usually a verbal model, and it is up to the mathematician to draw out the model and convert the verbal model to a mathematical one. For example, in air-to-air combat, pilots for many years had a system for classifying the state of the combat according to the relative positions of the aircraft (highly advantageous for aircraft 1, advantageous, neutral, etc.). The pilots also had ideas about transitions between states. My colleagues, R. Oberle, W. Nunn, and S. Naron converted the verbal model to one modeled using a semi-Markov process [10]. Their analytical methods are now in use on both coasts for the training of aircrews in air combat maneuvering.

4. What can an Applied Mathematician Offer?

By its very nature, applied mathematics is difficult to define and because this paper is supposed to be about people, I will instead

consider what an applied mathematician can offer. His first ability is that of model building. This means taking the verbal model of the operator and converting it to a mathematical one. The crucial step here is knowing what terms to throw away and what to keep when creating the model. Once a model is constructed, qualitative analysis, approximations, and interpretations of the analysis are all trademarks of the applied mathematician. Another trait is the ability to obtain numbers. A facility for computing is important since the operators want answers, and these are usually numerical in nature. Some knowledge of statistics is helpful.

Throughout his work in this type of setting, the goal of the applied mathematician is change. One is successful if he can change the way a problem is viewed or the way an operation is done. Too often, in too many settings, the goal of change is overlooked [11].

The final, and perhaps most important, characteristic that the mathematician needs is the desire to solve problems. One cannot be successful in this kind of work if he brings techniques and looks for problems that can be solved by his techniques. The problems are paramount, and one needs the versatility to bring in any techniques that can be used to solve the problems.

The particular academic training in courses and in research is not as important as the characteristics described above. One has to be willing to learn more and to learn whatever is needed for the job.

5. Some Examples of Problems

In this section, I discuss three problems, initiated by operators, that I worked on while I was the OEG Field Representative at the Whidbey Island (Washington) Naval Air Station. The aircraft operating out of Whidbey are the medium attack A-6 bomber and the EA-6B electronic warfare aircraft.

5.1 EA-6B Pod Availability

The EA-6B carries its jamming equipment in pods that are mounted on the wing stations. There are two transmitters per pod and each aircraft can carry up to five pods. Ideally, one would like all pods to work all the time. I shall refer to the overall fraction of the time that a pod worked as the availability of the pod. If the availability is low, then it is important to understand the causes of poor availability and ways to improve it.

Within a few weeks of my arrival in February, 1979 at Whidbey, a squadron returned home from a cruise with data on pod availability. They had set some simple criteria for a pod's being classified as working and had counted the fraction of pods that worked. They found low availability. These numbers were reported to the Admiral, who wanted further investigation. He tasked an officer, who came to me with the log book that the squadron had used and asked me to sift through the data and analyze it.

When the data were first reported as "a certain type of pod worked 70 percent of the time," one infers a picture of pod availability. The picture in this case is flipping a coin, a simple Bernoulli trial. As I analyzed that data, it became clear that a more complex picture was needed. I developed a series of Markov models for pod availability, the simplest of which is the following.

Assume that there are only two states for a pod, mission capable (MC) or not mission capable (NMC) and let $P_1(n)$, $P_0(n)$ be the probabilities that a pod is MC or NMC on the n th flight. Let p_{11} , p_{10} , p_{00} , p_{01} be the probability of transition $MC \rightarrow MC$, $MC \rightarrow NMC$, $NMC \rightarrow NMC$, $NMC \rightarrow MC$, respectively. Then

$$P_1(n+1) = P_1(n)p_{11} + P_0(n)p_{01} \quad . \quad (1)$$

Because $P_0(n) = 1 - P_1(n)$, equation 1 becomes

$$P_1(n+1) = p_{01} + P_1(n)(p_{11} - p_{01}) \quad . \quad (2)$$

The stationary solution of equation 2 is

$$P_{1S} = \frac{p_{01}}{p_{10} + p_{01}} \quad . \quad (3)$$

The p_{11} , which can be estimated from the data, have the following interpretations: p_{01} is a measure of the effectiveness of maintenance, because it characterizes the rate at which pods that are NMC return to the MC state; p_{11} is a measure of reliability, because it characterizes the probability that a pod which is MC remains MC. The long-term availability can be low if either p_{01} or p_{11} is low; however, ways to increase availability differ very much if the problem is in maintenance or reliability. If p_{01} is small, so that maintenance is the cause of poor availability, it may be possible to improve availability through increased attention to the problems of maintenance. Thus, one is faced with a command problem. If p_{11} is small, however, the problem of poor availability is related to the design of the equipment and improving availability may no longer be connected with operational aspects. I

found that p_{01} was about .2 or less, whereas p_{11} was about .8 or more, and concluded that availability could probably be improved by command attention to maintenance.

I checked other predictions of the simple two-state Markov model against the data and found that this simple model stood up well to scrutiny; so I presented my results to the command. I argued and convinced officers that the picture of the operations must be changed. Pod status is no longer analogous to flipping a coin, but more complicated verbal models are needed.

After the completion of this initial work, we began an in-depth study of the causes of low pod availability. We started using a four-state Markov chain model and collected data from seven of the ten EA-6B squadrons that go to the fleet. Along with operational data collected on aircrew debrief sheets, we had maintenance data sent back to Whidbey. I continued my analysis of these data, using any mathematical or statistical technique that I thought helpful.

By May, 1980, I was able to prepare a fairly substantial report on causes of poor pod availability. This report included information on the overall availability of pods, relationship between pod availability and aircraft, conclusions about reliability, and causes of poor maintenance and ways to improve maintenance. Pieces of this report appeared in various newsletters, I presented my results to the EA-6B

design review conference in August, 1980, and the report was sent to VAdm. McDonald, who is the Deputy Chief of Naval Operations for Air Warfare. This work certainly led to a change in the way that the problem was viewed; whether the overall availability will increase due to recommendations being followed remains to be seen.

5.2 Wings-Level Landings on Angle Decks

I became involved in this problem because I shared an office with an experienced A-6 pilot and overheard a conversation. My office mate was arguing with two new pilots about the possibility of a "wings-level" landing on a carrier deck. The young pilots asserted that in flight training they were given proof that it was possible to line up the aircraft with the landing deck of the carrier and then drive the ship with the proper velocity so that a pilot can land without making another correction. Because the older pilot did not believe these claims, even when he saw the proof, he asked me to take a look at the problem.

The relevant geometry is sketched in figure 2. A vector parallel to the angle deck is $I = (1, -1/\tan \alpha)$; a characteristic value is $\alpha = 10$ degrees. In typical operations, the ship is driven so that the resultant of ship and natural wind is "straight down the angle," i.e. parallel to I , with a magnitude of about 30 knots. Suppose that ship's velocity vector is $b = (b_x, b_y)$ and the wind is $w = (w_x, -w_y)$ so that the resultant wind is $r = (w_x - b_x, -w_y - b_y)$. We now want to drive the ship so

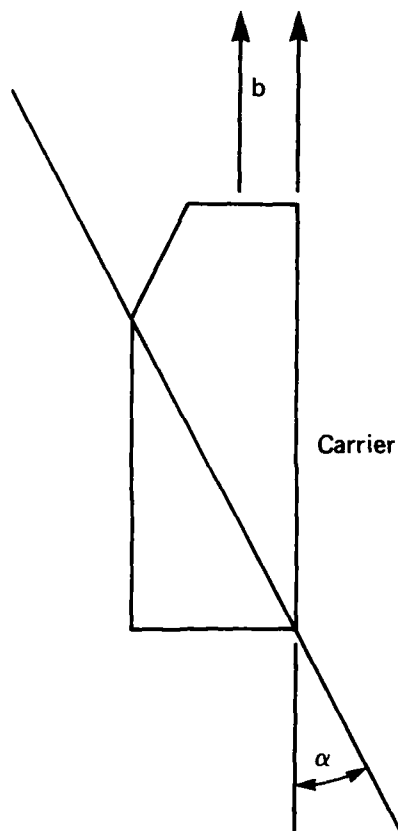


FIG. 2: GEOMETRY FOR THE ANGLE DECK
LANDING PROBLEM

that r is parallel to I and so that the magnitude of r is u . The two relevant unknown variables in this calculation are $|b|$, the required ship speed, and θ , the ship heading relative to the wind direction. The solution for these variables is

$$\left. \begin{aligned} |b| &= u \cos \alpha - |w| \cos \left[\arcsin \left(\frac{u \sin \alpha}{|w|} \right) \right] \\ \theta &= \arcsin \left(\frac{u \sin \alpha}{|w|} \right) . \end{aligned} \right\} (4)$$

Table 1 shows the ship's speed needed to keep a 30-knot wind down a 10-degree angle. From table 1 we conclude that it is possible to drive a ship properly except for low wind speeds.

Thus, it appears that wing-level landings are at least theoretically possible in a nonfluctuating world. Let us consider now the effects of fluctuations in the velocity of the ship and aircraft. In such a case, we can only ask for the probability of a wings-level landing. To do this, let $(S_x(t), S_y(t))$ and $(A_x(t), A_y(t))$ denote the positions of the ship and aircraft, respectively (assuming that they

TABLE 1

SHIP'S SPEED NEEDED TO KEEP A 30-KNOT
WIND DOWN THE ANGLE

<u>Wind speed (kt)</u>	<u>Speed of ship (kt)</u>	<u>Heading relative to wind (deg)</u>
30	0.0	10.0
20	10.2	15.1
10	21.0	31.4
6	26.6	60.3
<u><5.2</u>	No solution	

already are in the same plane). We assume that these variables satisfy the equations

$$\left. \begin{aligned} \dot{S}_x &= b_x + \xi_1(t) & \dot{A}_x &= w_x - v_x + \xi_3(t) \\ \dot{S}_y &= b_y + \xi_2(t) & \dot{A}_y &= w_y - v_y + \xi_4(t) \\ S_x(0) &= S_y(0) = 0 & A_x(0) &= a_x \quad A_y(0) = a_y \end{aligned} \right\} \quad (5)$$

In equation 5, the $\xi_i(t)$ are independent Gaussian white noise processes, (w_x, w_y) is the wind vector, (v_x, v_y) is the velocity vector of the aircraft, and (a_x, a_y) is the initial position of the aircraft. We assume that a_x and a_y are picked so that the aircraft is lined up with the angle deck; thus, $a_x = a_y \tan \alpha$. Furthermore, we assume that v_x and v_y are picked so that deterministically the aircraft can make a wings-level landing. To find them, we drop the noise terms in equation 5, set $S_x(t) = A_x(t)$ and $S_y(t) = A_y(t)$ to obtain the following equation for v_x :

$$(b_y + \sqrt{v^2 - v_x^2} - w_y) \tan \alpha = b_x + v_x - w_x \quad (6)$$

In equation 6, v is the speed of the aircraft; once v_x is known, $v_y = (v^2 - v_x^2)^{1/2}$.

Let us proceed with a "best case" calculation of the probability of a wings-level landing. Thus, we assume that b_x , b_y , ξ_1 , ξ_2 , w_x , and w_y are identically 0. In this case, the only noise is due to fluctuations in aircraft position. From equation 6 it is easy to see that $v_x = v/(1 + \tan^2 \alpha)^{1/2}$ and that $v_y = v_x/\tan \alpha$. Because the integral of white noise is normally distributed, we conclude from equation 5 that $A_x(t)$ is normally distributed with mean and variance

$$\mu_x(t) = a_x - v_x t \quad (7)$$

$$\sigma_x^2(t) = \sigma_1^2 t \quad (8)$$

where $\sigma_1^2 t$ is the variance of the Wiener process obtained by integrating $\xi_1(t)$. Similarly, $A_y(t)$ is normally distributed with mean and variance

$$\mu_y(t) = a_y - v_y t \quad (9)$$

$$\sigma_y^2(t) = \sigma_2^2 t \quad (10)$$

In this example, the ship stays at the origin. Thus, the probability of a wings-level landing is the joint probability that $A_x(t)$ and $A_y(t)$ are simultaneously approximately 0. By approximately, let us understand that they are within $2l$ of 0. The probability of a wings-level landing P_L can then be defined by

$$P_L = \max_t \left\{ \int_{-l}^l e^{-(x-\mu_x(t))^2/2\sigma_x^2(t)} \frac{dx}{\sqrt{2\pi\sigma_x^2(t)}} \right\} \quad (11)$$

$$\left\{ \int_{-l}^l e^{-(y-\mu_y(t))^2/2\sigma_y^2(t)} \frac{dy}{\sqrt{2\pi\sigma_y^2(t)}} \right\}.$$

In table 2, values of P_L are given for these parameters: $a_y = 1$ n.mi., $v = 120$ knots, $\alpha = 10$ degrees and various values of σ_1 and σ_2 . We assume that they are equal, so that $\sigma_1 = \sigma_2 = \sigma$ and define the intensity of fluctuations by $(\sigma_1^2 + \sigma_2^2)t_d/(a_x^2 + a_y^2)^{1/2}$ where t_d is the deterministic time to land the aircraft. When considering the results shown in table 2, one should also know that aviators are given badges for 100 landings on a carrier. Thus, an event that has a probability of occurrence of 10^{-4} each landing is rarely going to be observed in any

TABLE 2
PROBABILITY OF A WINGS-LEVEL LANDING

<u>Intensity of fluctuations</u>	<u>Probability of a wings-level landing</u>
0	1
1.67×10^{-6}	.97
4.17×10^{-5}	.11
1.67×10^{-4}	.024
4.17×10^{-3}	1.04×10^{-3}
.0167	2.7×10^{-4}
.0667	6.7×10^{-5}
.15	2.9×10^{-5}

aviator's career. The conclusion is that wings-level landings are possible, but highly improbable in the world modelled by equation 5.

5.3 Three-Bearing Method for Passive Localization

One of the missions of the EA-6B is that of passive localization of surface radar emitters. This localization is done by some sort of triangulation. The observing bearing between aircraft and emitter, θ_0 , is given by

$$\theta_0 = \theta_r + b(\theta_r) + \epsilon \quad (12)$$

where θ_r is the real bearing between the aircraft and emitter, $b(\theta_r)$ is a deterministic, but unknown bias function, and ϵ is a random noise term. For the EA-6B, $|b(\theta_r)|$ may be as large as 30 degrees, whereas the rms deviation of ϵ is about 1 to 3 degrees.

Since about 1945, triangulation problems with random noise received much attention (e.g. [12 and 13]), but the questions of the unknown deterministic bias were ignored. In the EA-6B, at least, the deterministic bias overrides the random noise in almost all cases, and yet until recently there was no way to treat it. Together with two officers, an EA-6B operator and an A-6 pilot, I developed the following method for localization in systems with an unknown deterministic bias

[14]. Its operational description is the following:

1. An initial value of the observed bearing, $\theta_{01} = \alpha$, is recorded.

2. The aircraft turns through an angle Δ_1 . If the observed bearing is positive (negative), the turn is positive (negative). The aircraft flies until the observed bearing θ_{02} is equal to α . The distance travelled s_1 is recorded.

3. The aircraft turns again through an angle Δ_2 and flies until the observed bearing θ_{03} is equal to α . The distance travelled s_2 is recorded.

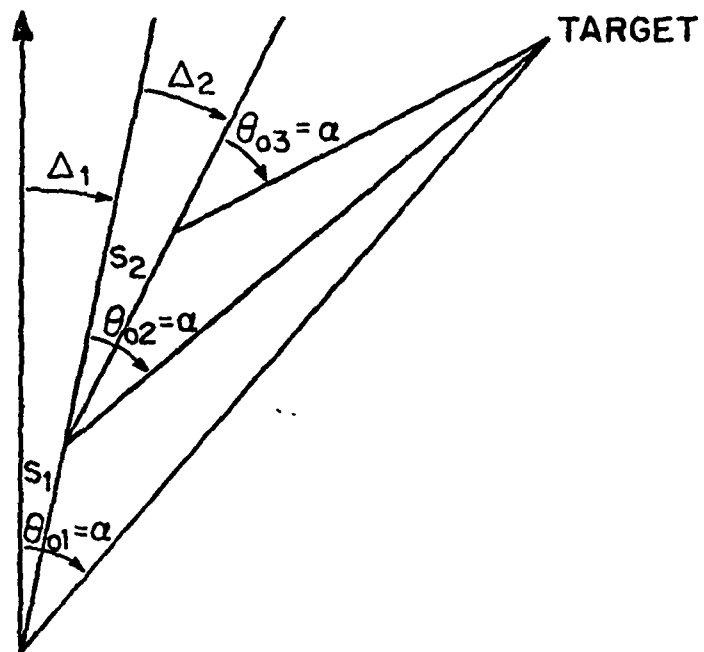
The geometry associated with this operation is shown in figure 3.

Referring to figure 3 and using the law of sines twice shows that

$$\frac{s_1}{\sin \Delta_1} = \frac{y}{\sin \theta_r} = \frac{R_1}{\sin(\theta_r - \Delta_1)} \quad (13)$$

$$\frac{s_2}{\sin \Delta_2} = \frac{R_1}{\sin \theta_r} = \frac{R_2}{\sin(\theta_r - \Delta_2)} .$$

(a) INITIAL HEADING



(b) INITIAL HEADING

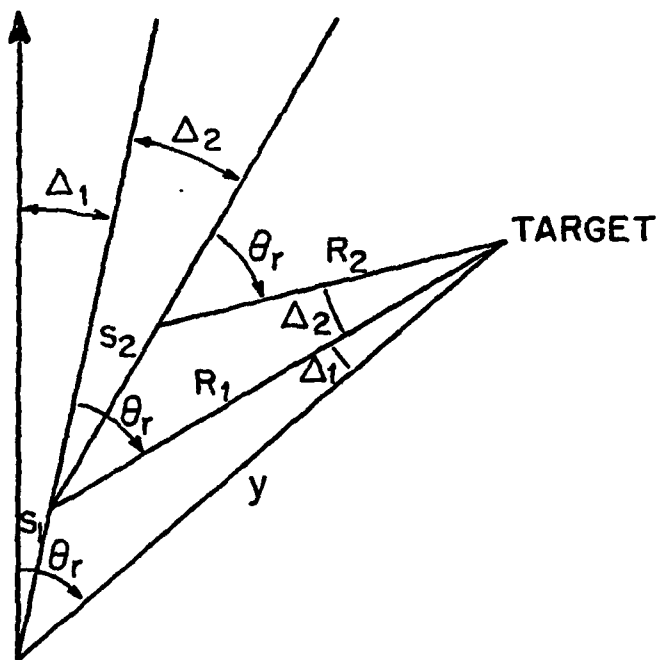


FIG. 3: CHARACTERIZATION OF THE THREE-BEARING METHOD

For the triangle with sides s_1 , y , and R_1

$$\cos \Delta_1 = \frac{y^2 + R_1^2 - s_1^2}{2yR_1} . \quad (14)$$

From equation 8

$$y = \frac{s_1 \sin \theta_r}{\sin \Delta_1} \quad \text{and} \quad \sin \theta_r = \frac{R_1 \sin \Delta_2}{s_2} \quad (15)$$

so that

$$y = \frac{s_1}{s_2} \cdot R_1 \cdot \frac{\sin \Delta_2}{\sin \Delta_1} = \gamma \eta R_1 . \quad (16)$$

Using equation 16 in equation 14 gives

$$\cos \Delta_1 = \frac{\gamma^2 \eta^2 R_1^2 + R_1^2 - s_1^2}{2\gamma \eta R_1^2} . \quad (17)$$

Equation 17 is cast into a dimensionless form by setting

$r_1 = R_1/s_2$. Then, after some simplification equation 17 becomes

$$r_1 = \frac{\gamma}{[\gamma^2 \eta^2 + 1 - 2\gamma \eta \cos \Delta_1]^{1/2}} . \quad (18)$$

From equation 15, $\sin \theta_r = r_1 \sin \Delta_2$ so that $\theta_r = \arcsin(r_1 \sin \Delta_2)$.

Because the arcsin is double-valued, more work is needed to evaluate

θ_r uniquely. In [14], it is shown that by switching to Cartesian coordinates one finds that

$$\tan \theta_r = \frac{[-s_2 \tan \Delta_2 \tan(\Delta_1 + \Delta_2) - (s_1 \sin \Delta_2) - (s_2 + s_1 \cos \Delta_2) \tan(\Delta_1 + \Delta_2)] \tan \Delta_2}{[-s_2 \tan(\Delta_1 + \Delta_2) + \tan \Delta_2 (s_2 + s_1 \cos \Delta_2 + s_1 \sin \Delta_2 \tan(\Delta_1 + \Delta_2))]} \quad (19)$$

so that θ_r is known uniquely. Once θ_r is known, from equation 13 we find that

$$R_2 = \frac{R_1 \sin(\theta_r - \Delta_2)}{\sin \theta_r} . \quad (20)$$

This method was flight tested in the summer of 1980 and was found to be operationally feasible and accurate to within 10 percent or less in range error. Thus, this method allows triangulation in systems with an unknown bias. In [14], it is shown how random errors can be incorporated into the method.

6. Conclusion

There are many problems and problem areas not mentioned in the above examples. A different analyst, by nature of taste and personality, would probably have worked on different problems, but I believe that the general principles are applicable to any field in which mathematics is to be applied. In addition to the principles listed in section 2, I believe that it is important to recognize the prevalence of stochastic effects and of unknown deterministic biases in the natural world. Too much analysis is done based on assumptions of a perfectly predictable world in which plans can be made at the outset and need not be changed.

Honesty requires that I point out some of the frustrations of this kind of work. The first is a lack of continuity. With good reason, an analyst should be at a field assignment no longer than about 2 or 3 years. Otherwise he becomes stale and too emotionally involved with his job to retain a high level of objectivity. But there is no reason to expect that your replacement will follow up on projects that you have started. In general, that will not happen and it can be disappointing. The second frustration is that, as with all other jobs, there is drudgery in this job also. Not every day contains excitement. A third type of frustration is that often there is little feedback about the analysis one has done. The analyst finds himself forcing people to read his work and respond to it. Sometimes this is an

unpleasant task. These frustrations appear in almost any job, and surely some would appear in any academic job.

The principles that make OEG effective undoubtedly will work in any type of nonacademic setting and point the way for mathematicians to be effective in the use of their tools.

ACKNOWLEDGEMENTS

For reading and commenting on the manuscript, I thank J. Beder, D. Cope, A. Krener, S. Mangel, R. Plant, and D. Wills. The paper would not have been written without the encouragement of D. Ludwig and P. E. DePoy. C. Clark pointed out the Karl Popper quotation to me.

REFERENCES

- [1] Morse, P., In at the Beginnings: A Physicist's Life. MIT Press, 1977
- [2] Morse, P. and Kimball, G., "Methods of Operations Research," OEG Report 54, Superintendent of Documents, 1946
- [3] Sternhell, C. and Thorndike, A., "Antisubmarine Warfare in World War II," OEG Report 51, Reprinted 1977
- [4] Koopman, B. O., "Search and Screening," OEG Report 56, 1946. Revised version published by Pergamon, 1980
- [5] Ackoff, R., "The Future of Operational Research is Past," J. Oper. Res. Soc. 30, 193 (1979)
- [6] Ackoff, R., "Resurrecting Operational Research," J. Oper. Res. Soc. 30, 189 (1979)
- [7] Simon, H., The Science of the Artificial, M.I.T. Press, 1969
- [8] R. Ackoff, The Art of Problem Solving, Wiley, 1979
- [9] Stone, L. D., The Theory of Optimal Search, Academic Press, 1975
- [10] Nunn, W. R., Oberle, R. A., "Evaluating Air Combat Maneuvering," Vol 1, Center for Naval Analyses Study 1077, 1976
- [11] Beltrami, E., Models for Public Systems Analysis, Academic Press, 1977
- [12] Daniels, M., "Statistical Theory of DF Fixing," J. IEE London 94:762-770 (1947)
- [13] Gelb, A., Applied Optimal Estimation, M.I.T. Press, Cambridge, Mass, 1975
- [14] Mangel, M., "Three-Bearing Method for Passive Localization on Systems With an Unknown Bias," IEEE Trans. Aerospace Systems

CNA PROFESSIONAL PAPERS - 1978 TO PRESENT*

- PP 211
Mizrahi, Maurice M., "On Approximating the Circular Coverage Function," 14 pp., Feb 1978, AD A054 429
- PP 212
Mangel, Marc, "On Singular Characteristic Initial Value Problems with Unique Solution," 20 pp., Jun 1978, AD A058 535
- PP 213
Mangel, Marc, "Fluctuations in Systems with Multiple Steady States- Application to Lanchester Equations," 12 pp., Feb 78 (Presented at the First Annual Workshop on the Information Linkage Between Applied Mathematics and Industry, Naval PG School, Feb 23-25, 1978), AD A071 472
- PP 214
Weinland, Robert G., "A Somewhat Different View of the Optimal Naval Posture," 37 pp., Jun 1978 (Presented at the 1976 Convention of the American Political Science Association (APSA)/US Panel on "Changing Strategic Requirements and Military Posture", Chicago, Ill., September 2, 1976), AD A056 228
- PP 215
Colle, Russell C., "Comments on: Principles of Information Retrieval by Manfred Kochen," 10 pp., Mar 78 (Published as a Letter to the Editor, Journal of Documentation, Vol. 31, No. 4, pages 298-301), December 1975), AD A054 426
- PP 216
Colle, Russell C., "Lotka's Frequency Distribution of Scientific Productivity," 18 pp., Feb 1978 (Published in the Journal of the American Society for Information Science, Vol. 28, No. 6, pp. 366-370, November 1977), AD A054 425
- PP 217
Colle, Russell C., "Bibliometric Studies of Scientific Productivity," 17 pp., Mar 78 (Presented at the Annual meeting of the American Society for Information Science held in San Francisco, California, October 1976), AD A054 442
- PP 218 - Classified
- PP 219
Huntzinger, R. LeVar, "Market Analysis with Rational Expectations: Theory and Estimation," 60 pp., Apr 78, AD A054 422
- PP 220
Maurer, Donald E., "Diagonalization by Group Matrices," 26 pp., Apr 78, AD A054 443
- PP 221
Weinland, Robert G., "Superpower Naval Diplomacy in the October 1973 Arab-Israeli War," 76 pp., Jun 1978 (Published in Seapower in the Mediterranean: Political Utility and Military Constraints, The Washington Papers No. 61, Beverly Hills and London: Sage Publications, 1979) AD A055 564
- PP 222
Mizrahi, Maurice M., "Correspondence Rules and Path Integrals," 30 pp., Jun 1978 (Invited paper presented at the CNRS meeting on "Mathematical Problems in Feynman's Path Integrals," Marseille, France, May 22-26, 1978) (Published in Springer Verlag Lecture Notes in Physics, 106, (1979), 234-253) AD A055 536
- PP 223
Mangel, Marc, "Stochastic Mechanics of Molecule-Molecule Reactions," 21 pp., Jun 1978, AD A056 227
- PP 224
Mangel, Marc, "Aggregation, Bifurcation, and Extinction in Exploited Animal Populations," 48 pp., Mar 1978, AD A058 536
*Portions of this work were started at the Institute of Applied Mathematics and Statistics, University of British Columbia, Vancouver, B.C., Canada
- PP 225
Mangel, Marc, "Oscillations, Fluctuations, and the Hopf Bifurcation," 43 pp., Jun 1978, AD A058 537
*Portions of this work were completed at the Institute of Applied Mathematics and Statistics, University of British Columbia, Vancouver, Canada.
- PP 226
Raiston, J. M. and J. W. Mann, "Temperature and Current Dependence of Degradation in Red-Emitting GaP LEDs," 34 pp., Jun 1978 (Published in Journal of Applied Physics, 50, 3630, May 1979) AD A058 538
*Bell Telephone Laboratories, Inc.
- PP 227
Mangel, Marc, "Uniform Treatment of Fluctuations at Critical Points," 50 pp., May 1978, AD A058 539
- PP 228
Mangel, Marc, "Relaxation at Critical Points: Deterministic and Stochastic Theory," 54 pp., Jun 1978, AD A058 540
- PP 229
Mangel, Marc, "Diffusion Theory of Reaction Rates, I: Formulation and Einstein-Smoluchowski Approximation," 50 pp., Jan 1978, AD A058 541
- PP 230
Mangel, Marc, "Diffusion Theory of Reaction Rates, II Ornstein-Uhlenbeck Approximation," 34 pp., Feb 1978, AD A058 542
- PP 231
Wilson, Desmond P., Jr., "Naval Projection Forces: The Case for a Responsive MAF," Aug 1978, AD A054 543
- PP 232
Jacobson, Louis, "Can Policy Changes Be Made Acceptable to Labor?" Aug 1978 (Submitted for publication in Industrial and Labor Relations Review), AD A061 528

*CNA Professional Papers with an AD number may be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22151. Other papers are available from the Management Information Office, Center for Naval Analyses, 2000 North Beauregard Street, Alexandria, Virginia 22311. An index of Selected Publications is also available on request. The index includes a listing of Professional Papers; with abstracts; issued from 1969 to June 1981.

- PP 233
Jacobson, Louis, "An Alternative Explanation of the Cyclical Pattern of Quits," 23 pp., Sep 1978
- PP 234 - Revised
Jondrow, James and Levy, Robert A., "Does Federal Expenditure Displace State and Local Expenditure: The Case of Construction Grants," 25 pp., Oct 1979, AD A061 529
- PP 235
Mizrahi, Maurice M., "The Semiclassical Expansion of the Anharmonic-Oscillator Propagator," 41 pp., Oct 1978 (Published in Journal of Mathematical Physics 20 (1979) pp. 844-855), AD A061 538
- PP 237
Maurer, Donald, "A Matrix Criterion for Normal Integral Bases," 10 pp., Jan 1979 (Published in the Illinois Journal of Mathematics, Vol. 22 (1978), pp. 672-681)
- PP 238
Utgoff, Kathleen Classen, "Unemployment Insurance and The Employment Rate," 20 pp., Oct 1978 (Presented at the Conference on Economic Indicators and Performance: The Current Dilemma Facing Government and Business Leaders, presented by Indiana University Graduate School of Business). AD A061 527
- PP 239
Trost, R. P. and Werner, J. T., "The Effects of Military Occupational Training on Civilian Earnings: An Income Selectivity Approach," 38 pp., Nov 1979k, AD A077 831
- PP 240
Powers, Bruce, "Goals of the Center for Naval Analyses," 13 pp., Dec 1978, AD A063 759
- PP 241
Mangel, Marc, "Fluctuations at Chemical Instabilities," 24 pp., Dec 1978 (Published in Journal of Chemical Physics, Vol. 69, No. 8, Oct 15, 1978). AD A063 787
- PP 242
Simpson, William R., "The Analysis of Dynamically Interactive Systems (Air Combat by the Numbers)," 160 pp., Dec 1978, AD A063 760
- PP 243
Simpson, William R., "A Probabilistic Formulation of Murphy Dynamics as Applied to the Analysis of Operational Research Problems," 18 pp., Dec 1978, AD A063 761
- PP 244
Sherman, Allan and Horowitz, Stanley A., "Maintenance Costs of Complex Equipment," 20 pp., Dec 1978 (Published By The American Society of Naval Engineers, Naval Engineers Journal, Vol. 91, No. 6, Dec 1979) AD A071 473
- PP 245
Simpson, William R., "The Accelerometer Methods of Obtaining Aircraft Performance from Flight Test Data (Dynamic Performance Testing)," 403 pp., Jun 1979, AD A075 226
- PP 246
Brechling, Frank, "Layoffs and Unemployment Insurance," 35 pp., Feb 1979 (Presented at the Nber Conference on "Low Income Labor Markets," Chicago, Jun 1978), AD A096 629
- PP 248
Thomas, James A., Jr., "The Transport Properties of Dilute Gases in Applied Fields," 183 pp., Mar 1979, AD A096 464
- PP 249
Glasser, Kenneth S., "A Secretary Problem with a Random Number of Choices," 23 pp., Mar 1979
- PP 250
Mangel, Marc, "Modeling Fluctuations in Macroscopic Systems," 26 pp., Jun 1979
- PP 251
Trost, Robert P., "The Estimation and Interpretation of Several Selectivity Models," 37 pp., Jun 1979, AD A075 941
- PP 252
Nunn, Walter R., "Position Finding with Prior Knowledge of Covariance Parameters," 5 pp., Jun 1979 (Published in IEEE Transactions on Aerospace & Electronic Systems, Vol. AES-15, No. 3, Mar 1979)
- PP 253
Glasser, Kenneth S., "The d-Choice Secretary Problem," 32 pp., Jun 1979, AD A075 225
- PP 254
Mangel, Marc and Quanbeck, David B., "Integration of a Bivariate Normal Over an Offset Circle," 14 pp., Jun 1979, AD A096 471
- PP 255 - Classified, AD B051 441L
- PP 256
Maurer, Donald E., "Using Personnel Distribution Models," 27 pp., Feb 1980, AD A082 218
- PP 257
Thaler, R., "Discounting and Fiscal Constraints: Why Discounting is Always Right," 10 pp., Aug 1979, AD A075 224
- PP 258
Mangel, Marc S. and Thomas, James A., Jr., "Analytical Methods in Search Theory," 86 pp., Nov 1979, AD A077 832
- PP 259
Glass, David V.; Hsu, Ih-Ching; Nunn, Walter R., and Perin, David A., "A Class of Commutative Markov Matrices," 17 pp., Nov 1979, AD A077 833
- PP 260
Mangel, Marc S. and Cope, Davis K., "Detection Rate and Sweep Width in Visual Search," 14 pp., Nov 1979, AD A077 834
- PP 261
Vila, Carlos L.; Zvijac, David J. and Ross, John, "Frank-Condon Theory of Chemical Dynamics. VI. Angular Distributions of Reaction Products," 14 pp., Nov 1979 (Reprinted from Journal Chemical Phys. 70(12), 15 Jun 1979), AD A076 287
- PP 262
Petersen, Charles C., "Third World Military Elites in Soviet Perspective," 50 pp., Nov 1979, AD A077 835
- PP 263
Robinson, Kathy L., "Using Commercial Tankers and Container-ships for Navy Underway Replenishment," 25 pp., Nov 1979, AD A077 836

PP 264

Weinland, Robert G., "The U.S. Navy In the Pacific: Past, Present, and Glimpses of the Future," 31 pp., Nov 1979 (Delivered at the International Symposium on the Sea, sponsored by the International Institute for Strategic Studies, The Brookings Institution and the Yomiuri Shimbun, Tokyo, 16-20 Oct 1978) AD A066 837

PP 265

Weinland, Robert G., "War and Peace In the North: Some Political Implications of the Changing Military Situation in Northern Europe," 18 pp., Nov 1979 (Prepared for presentation to the Conference of the Nordic Balance in Perspective: The Changing Military and Political Situation," Center for Strategic and International Studies, Georgetown University, Jun 15-16, 1978) AD A077 838

PP 266

Utgoft, Kathy Classen, and Brechling, Frank, "Taxes and Inflation," 25 pp., Nov 1979, AD A081 194

PP 267

Trost, Robert P., and Vogel, Robert C., "The Response of State Government Receipts to Economic Fluctuations and the Allocation of Counter-Cyclical Revenue Sharing Grants," 12 pp., Dec 1979 (Reprinted from the Review of Economics and Statistics, Vol. LXI, No. 3, August 1979)

PP 268

Thomson, James S., "Seaport Dependence and Inter-State Cooperation: The Case of Sub-Saharan Africa," 141 pp., Jan 1980, AD A081 193

PP 269

Weiss, Kenneth G., "The Soviet Involvement In the Ogaden War," 2 pp., Jan 1980 (Presented at the Southern Conference on Slavic Studies in October, 1979), AD A082 219

PP 270

Ramnek, Richard, "Soviet Policy In the Horn of Africa: The Decision to Intervene," 52 pp., Jan 1980 (To be published in "The Soviet Union In the Third World: Success or Failure," ed. by Robert H. Donaldson, Westview Press, Boulder, Co., Summer 1980), AD A081 195

PP 271

McConnell, James, "Soviet and American Strategic Doctrines: One More Time," 43 pp., Jan 1980, AD A081 192

PP 272

Weiss, Kenneth G., "The Azores In Diplomacy and Strategy, 1940-1945," 46 pp., Mar 1980, AD A085 094

PP 273

Nakada, Michael K., "Labor Supply of Wives with Husbands Employed Either Full Time or Part Time," 39 pp., Mar 1980, AD A082 220

PP 274

Nunn, Walter R., "A Result In the Theory of Spiral Search," 9 pp., Mar 1980

PP 275

Goldberg, Lawrence, "Recruiters Advertising and Navy Enlistments," 34 pp., Mar 1980, AD A082 221

PP 276

Goldberg, Lawrence, "Delaying an Overhaul and Ship's Equipment," 40 pp., May 1980, AD A085 095

PP 277

Mengel, Marc, "Small Fluctuations In Systems with Multiple Limit Cycles," 19 pp., Mar 1980 (Published In SIAM J. Appl. Math., Vol. 38, No. 1, Feb 1980) AD A086 229

PP 278

Mizrachi, Maurice, "A Targeting Problem: Exact vs. Expected-Value Approaches," 23 pp., Apr 1980, AD A085 096

PP 279

Walt, Stephen M., "Causal Inferences and the Use of Force: A Critique of Force Without War," 50 pp., May 1980, AD A085 097

PP 280

Goldberg, Lawrence, "Estimation of the Effects of A Ship's Scheduling on the Failure Rate of Its Equipment: An Application of Econometric Analysis," 25 pp., Apr 1980, AD A085 098

PP 281

Mizrachi, Maurice M., "Comment on 'Discretization Problems of Functional Integrals in Phase Space'," 2 pp., May 1980, published in "Physical Review D", Vol. 22 (1980), AD A094 994

PP 283

Dismukes, Bradford, "Expected Demand for the U.S. Navy to Serve as An Instrument of U.S. Foreign Policy: Thinking About Political and Military Environmental Factors," 30 pp., Apr 1980, AD A085 099

PP 284

J. Kellison,* W. Nunn, and U. Sumita,** "The Laguerre Transform," 119 pp., May 1980, AD A085 100
*The Graduate School of Management, University of Rochester and the Center for Naval Analyses
**The Graduate School of Management, University of Rochester

PP 285

Ramnek, Richard B., "Superpower Security Interests In the Indian Ocean Area," 26 pp., Jun 1980, AD A087 113

PP 286

Mizrachi, Maurice M., "On the WKB Approximation to the Propagator for Arbitrary Hamiltonians," 25 pp., Aug 1980 (Published In Journal of Math. Phys., 22(1) Jan 1981), AD A091 307

PP 287

Cope, Davis, "Limit Cycle Solutions of Reaction-Diffusion Equations," 35 pp., Jun 1980, AD A087 114

PP 288

Goldman, Walter, "Don't Let Your Slides Flip You: A Painless Guide to Visuals That Really Aid," 28 pp., Oct 1980, AD A092 732

PP 289

Robinson, Jack, "Adequate Classification Guidance - A Solution and a Problem," 7 pp., Aug 1980, AD A091 212

PP 290

Watson, Gregory H., "Evaluation of Computer Software in an Operational Environment," 17 pp., Aug 1980, AD A091 213

PP 291

Maddele, G. S.* and Trost, R. P., "Some Extensions of the Harlowe Press Model," 17 pp., Oct 1980, AD A091 946
*University of Florida

- PP 292
Thoms, James A., Jr., "The Transport Properties of Binary Gas Mixtures in Applied Magnetic Fields," 10 pp., Sept 1980 (Published in *Journal of Chemical Physics* 72(10), 15 May 1980)
- PP 293
Thoms, James A., Jr., "Evaluation of Kinetic Theory Collision Integrals Using the Generalized Phase Shift Approach," 12 pp., Sept 1980 (Printed in *Journal of Chemical Physics* 72(10), 15 May 1980)
- PP 294
Roberts, Stephen S., "French Naval Policy Outside of Europe," 30 pp., Sept 1980 (Presented at the Conference of the Section on Military Studies, International Studies Association Kilauea Island, S.C.), AD A091 306
- PP 295
Roberts, Stephen S., "An Indicator of Informal Empire: Patterns of U.S. Navy Cruising on Overseas Stations, 1869-1897," 40 pp., Sept 1980 (Presented at Fourth Naval History Symposium, US Naval Academy, 26 October 1979, AD A091 316)
- PP 296
Dismukes, Bradford and Petersen, Charles C., "Maritime Factors Affecting Iberian Security," (*Factores Maritimos Que Afectan La Seguridad Ibeica*) 14 pp., Oct 1980, AD A092 733
- PP 297 - Classified
- PP 298
Mizrahi, Maurice M., "A Markov Approach to Large Missile Attacks," 31 pp., Jan 1981, AD A096,159
- PP 299
Jondrow, James M. and Levy, Robert A., "Wage Leadership in Construction, 19 pp., Jan 1981, AD A094 797
- PP 300
Jondrow, James and Schmidt, Peter, * "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model," 11 pp., Jan 1981, AD A096 160
*Michigan State University
- PP 301
Jondrow, James M., Levy, Robert A. and Hughes, Claire, "Technical Change and Employment in Steel, Autos, Aluminum, and Iron Ore, 17 pp., Mar 1981, AD A099 394
- PP 302
Jondrow, James M. and Levy, Robert A., "The Effect of Imports on Employment Under Rational Expectations," 19 pp., Apr 1981, AD A099 392
- PP 303
Thomson, James, "The Rarest Commodity in the Coming Resource Wars," 3 pp., Aug 1981 (Published in the *Washington Star*, April 13, 1981)
- PP 304
Duffy, Michael K.; Greenwood, Michael J.* and McDowell, John M.,** "A Cross-Sectional Model of Annual Interregional Migration and Employment Growth: Intertemporal Evidence of Structural Change, 1958-1975," 31 pp., Apr 1981, AD A099 393
*University of Colorado
**Arizona State University
- PP 305
Nunn, Laura H., "An Introduction to the Literature of Search Theory," 32 pp., Jun 1981
- PP 306
Anger, Thomas E., "What Good Are Warfare Models?" 7 pp., May 1981
- PP 307
Thomson, James, "Dependence, Risk, and Vulnerability," 43 pp., Jun 1981
- PP 308
Mizrahi, M.M., "Correspondence Rules and Path Integrals," Jul 1981. Published in "*Nuovo Cimento B*", Vol. 61 (1981)
- PP 309
Weinland, Robert G., "An (The?) Explanation of the Soviet Invasion of Afghanistan," 44 pp., May 1981
- PP 310
Stanford, Janette M. and Tai Te Wu,* "A Predictive Method for Determining Possible Three-dimensional Foldings of Immunoglobulin Backbones Around Antibody Combining Sites," 19 pp., Jun 1981 (Published in *J. theor. Biol.* (1981) 88, 421-439
*Northwestern University, Evanston, IL
- PP 311
Bowes, Marianne, Brechling, Frank P. R., and Utgoff, Kathleen P. Classen, "An Evaluation of UI Funds," 13 pp., May 1981 (Published in *National Commission on Unemployment Compensation's Unemployment Compensation: Studies and Research, Volume 2, July 1980*)
- PP 312
Jondrow, James; Bowes, Marianne and Levy, Robert, "The Optimum Speed Limit," 23 pp., May 1981
- PP 313
Roberts, Stephen S., "The U.S. Navy in the 1980s," 36 pp., Jul 1981
- PP 314
Jehn, Christopher; Horowitz, Stanley A. and Lockman, Robert F., "Examining the Draft Debate," 20 pp., Jul 1981
- PP 315
Buck, Ralph V., Capt., "Le Catastrophe by any other name...", 4 pp., Jul 1981
- PP 316
Roberts, Stephen S., "Western European and NATO Navies, 1980," 20 pp., Aug 1981
- PP 317
Roberts, Stephen S., "Superpower Naval Crisis Management in the Mediterranean," 35 pp., Aug 1981
- PP 318
Vega, Milan N., "Yugoslavia and the Soviet Policy of Force in the Mediterranean Since 1961," 187 pp., Aug 1981
- PP 319
Smith, Michael W., "Antiair Warfare Defense of Ships at Sea," 46 pp., Sep 1981 (This talk was delivered at the Naval Warfare System and Technology Conference of the American Institute of Aeronautics and Astronautics in Washington on December 12, 1980; in Boston on January 20, 1981; and in Los Angeles on June 12, 1981.)

- PP 320
Trost, R. P., Lurie, Philip and Berger, Edward, "A Note on Estimating Continuous Time Decision Models," 15 pp., Sep 1981
- PP 321
Duffy, Michael K. and Ladman, Jerry R., "The Simultaneous Determination of Income and Employment in United States--Mexico Border Region Economies," 34 pp., Sep 1981
*Associate Professor of Economics, Arizona State University, Tempe, AZ.
- PP 322
Warner, John T., "Issues in Navy Manpower Research and Policy: An Economist's Perspective," 66 pp., Dec 1981
- PP 323
Bomse, Frederick M., "Generation of Correlated Log-Normal Sequences for the Simulation of Clutter Echoes," 33 pp., Dec 1981
- PP 324
Horowitz, Stanley A., "Quantifying Seapower Readiness," 6 pp., Dec 1981 (Published in Defense Management Journal, Vol. 18, No. 2)
- PP 327
Hammon, Collin, Capt., USN and Graham, David R., Dr., "Estimation and Analysis of Navy Shipbuilding Program Disruption Costs," 12 pp., Mar 1980
- PP 328
Weinland, Robert G., "Northern Waters: Their Strategic Significance," 27 pp., Dec 1980
- PP 329
Mangel, Marc, "Applied Mathematicians And Naval Operators," 40 pp., Mar 1982 (Revised)
- PP 330
Lodman, Robert F., "Alternative Approaches to Attrition Management," 30 pp., Jan 1982
- PP 331
Roberts, Stephen S., "The Turkish Straits and the Soviet Navy in the Mediterranean," 15 pp., Mar 1982 (Published in Navy International)
- PP 332
Jehn, Christopher, "The RDF and Amphibious Warriors," 36 pp., Mar 1982
- PP 333
Lee, Lung-Fel and Trost, Robert P., "Estimation of Some Limited Dependent Variable Models with Application to Housing Demand," 26 pp., Jan 1982. (Published in Journal of Econometrics 8 (1978) 357-382)
- PP 334
Kenny, Lawrence W., Lee, Lung-Fel, Maddala, G. S., and Trost R. P., "Returns to College Education: An Investigation of Self-Selection Bias Based on the Project Talent Data," 15 pp., Jan 1982. (Published in International Economic Review, Vol. 20, No. 3, October 1979)
- PP 335
Lee, Lung-Fel, G.S. Maddala, and R. P. Trost, "Asymptotic Covariance Matrices of Two-Stage Probit and Two-Stage Tobit Methods for Simultaneous Equations Models with Selectivity," 13 pp., Jan 1982. (Published in Econometrica, Vol. 48, No. 2 (March, 1980))
- PP 336
O'Neill, Thomas, "Mobility Fuels for the Navy," 13 pp., Jan 1982. (Accepted for publication in Naval Institute Proceedings)
- PP 337
Warner, John T. and Goldberg, Matthew S., "The Influence of Non-Pecuniary Factors on Labor Supply," 23 pp., Dec 1981
- PP 339
Wilson, Desmond P., "The Persian Gulf and the National Interest," 11 pp., Feb 1982
- PP 340
Lurie, Philip, Trost, R. P., and Berger, Edward, "A Method for Analyzing Multiple Spell Duration Data," 34 pp., Feb 1982
- PP 341
Trost, Robert P. and Vogel, Robert C., "Prediction with Pooled Cross-Section and Time-Series Data: Two Case Studies," 6 pp., Feb 1982
- PP 342
Lee, Lung-Fel, Maddala, G. S., and Trost, R. P., "Testing for Structural Change by D-Methods in Switching Simultaneous Equations Models," 5 pp., Feb 1982
- PP 343
Goldberg, Matthew S., "Projecting the Navy Enlisted Force Level," 9 pp., Feb 1982
- PP 344
Fletcher, Jean, W., "Navy Quality of Life and Reenlistment," 13 pp., Nov 1981
- PP 345
Utgoft, Kathy and Thaler, Dick, "The Economics of Multi Year Contracting," 47 pp., Mar 1982. (Presented at the 1982 Annual Meeting of the Public Choice Society, San Antonio, Texas, March 5-7, 1982)
- PP 346
Rostker, Bernard, "Selective Service and the All-Volunteer Force," 23 pp., Mar 1982
- PP 347
McConnell, James, M., "A Possible Counterforce Role for the Typhoon," 24 pp., Mar 1982
- PP 348
Jondrow, James, Trost, Robert, "An Empirical Study of Production Inefficiency in the Presence of Errors-in-The-Variables," 14 pp., Feb 1982
- PP 349
W. H. Breckenridge, O. Kim Majum, "Collisional Intra-multiplet Relaxation of Cd(5s³p² P_{0,1,2}) by Alkane Hydrocarbons," 7 pp., Jul 1981. (Published in Journal of Chemical Physics, 76(4), 15 Feb 1982)

✓ PP 350
Levin, Marc, "A Method for Increasing the Firepower of Virginia Class Cruisers," 10 pp., Apr 1982. (To be published in U.S. Naval Institute Proceedings)

PP 351
Coutre, S. E., Stanford, J. M.; Havis, J. G.; Stevens, P. W.; Wu, T. T., "Possible Three-Dimensional Backbone Folding Around Antibody Combining Site of Immunoglobulin MOPC 167," 18 pp., Apr 1982. (Published in Journal of Theoretical Biology)

✓ PP 352
Berfoot, C. Bernard, "Aggregation of Conditional Absorbing Markov Chains," 7 pp., June 1982 (Presented to the Sixth European Meeting on Cybernetics and Systems Research, held at the University of Vienna, Apr 1982.

✓ PP 353
Berfoot, C. Bernard, "Some Mathematical Methods for Modeling the Performance of a Distributed Data Base System," 18 pp./ June 1982. (Presented to the International Working Conference on Model Realism, held at Bad Honnek, West Germany, Apr 1982.